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Revised cement-content control limits are proposed and a specific frequency of testing and use of control charts are recommended.

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HIGHWAY RESEARCH REPORT

A STATISTICAL ANALYSIS OF PERCENT OF CEMENT IN CEMENT TREATED BASE

67-40

STATE OF CALIFORNIA

TRANSPORTATION AGENCY

DEPARTMENT OF PUBLIC WORKS

DIVISION OF HIGHWAYS

MATERIALS AND RESEARCH DEPARTMENT

RESEARCH REPORT

NO. M & R 631133-7

Prepared in Cooperation with the U.S. Department of Commerce, Bureau of Public Roads April 1967

State of California
Department of Public Works
Division of Highways
Materials and Research Department

RESEARCH REPORT

A STATISTICAL ANALYSIS OF PERCENT OF CEMENT IN CEMENT TREATED BASE

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Prepared in Cooperation with the
U. S. Department of Transportation, Bureau of [illegible]

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This is one in a series of interim reports of a research project to statistically evaluate variations in construction material. This work was done under the 1964-65 Work Program HPR-1(2), 6 F-1-1 in cooperation with the U. S. Department of Transportation, Bureau of Public Roads.

The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the Bureau of Public Roads.

ABSTRACT

A statistical analysis of the cement content of plant-mixed Cement Treated Base is reported. Three construction projects in different areas of California were sampled and the test results analyzed.

It was concluded that the current requirements on the cement content are restrictive and are not being met; however, the compressive strength of the materials and, consequently, the quality of the CTB is adequate.

Revised cement-content control limits are proposed and a specific frequency of testing and use of control charts are recommended.

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INTRODUCTION

With the trend towards the statistical approach to quality control in highway construction, the California Division of Highways, in cooperation with the Bureau of Public Roads, is engaged in a project to study various materials. This project consists of (1) evaluation of existing control procedures through statistical surveys, and (2) preparation and evaluation of some trial statistical specifications for various construction materials. Test Method No. Calif. 338, "Determination of Cement Content in Cement Treated Aggregate by the Method of Titration", was included as one phase of this project. This report, which is an interim report for the larger research study, is limited to the discussion of this one test method.

Test Method No. Calif. 338 was adopted in 1960 by the California Division of Highways as a means of controlling the uniformity of mixing and distribution of cement in Cement Treated Base (CTB) material during construction. The lack of a rapid field test prior to this time made it difficult and often next to impossible to check cement quantity and distribution. This test method actually consists of two different titration procedures. The first, an acid-base titration procedure, [illegible] ... and react to hydrochloric acid; the second, a constant neutralization method, must be used when aggregates are encountered which do react to hydrochloric acid.

CONCLUSIONS

It is concluded from the data gathered in this study that:

1. The Titration Test as described in Test Method No. Calif. 338 is accurate and reproducible for determining the amount of cement in a sample of Cement Treated Base.
2. The procedure followed when sampling Cement Treated Base, particularly from a windrow, is very important. Erroneous test data will, of course, result from non-representative samples. However, when the sampling is done properly, very little sampling variance is introduced into the final test results. Less sampling error is introduced when obtaining samples from material which has passed through a spreader box than when sampling from a windrow.

3. Based on this study, the variation of cement presently allowed in California specifications appears to be too restrictive. The absolute requirement is not always being met even on well controlled construction projects.
4. It is concluded (from the job control compressive strength records of the three projects studied) that sufficient cement is being used to compensate for the variation in cement distribution.
5. Due to testing and sampling errors, the data recorded for Project Two are not representative of the actual work done on the project and do not represent the accuracy of the test method.

SAMPLING AND TESTING

The sampling and testing plan used for this research was essentially the plan presented to the various state highway departments by the U. S. Bureau of Public Roads through their regional workshops. The full details of this statistical survey outline may be found in either Reference 1 or 2. In general, it consisted of randomly locating fifty sampling locations on each of three projects; taking two independent samples at each testing location; and splitting the samples for independent tests on each sample portion. Thus, a total of four results were available for each sampling location. The duplicate sampling provided a measure of the variance in the sampling process and the duplicate testing on each sample provided a measure of the reproducibility of the test.

At the beginning of this project, it was observed that some of the personnel assigned to do the sampling had the misconception that a random sample is a haphazardly obtained portion of the material taken at some unscheduled location. On the contrary, a random sample must be taken with care and accuracy and at a location specifically chosen by an accepted random procedure. For this study a table of random numbers was used to randomly determine the sampling location.

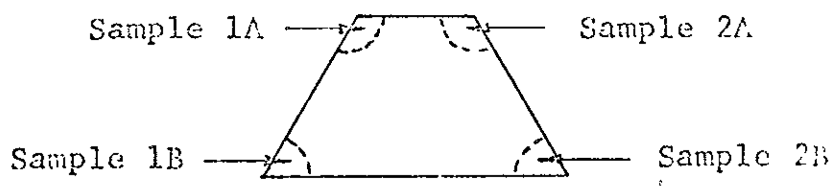
MATERIALS AND PROCEDURES

Three construction projects using plant-mixed Cement Treated Base were selected for this study. The mixing, handling and sampling techni[illegible] as well as the equipment, differed to [illegible] of the projects.

Project One:

On Project One a 3,000 pound Barber-Greene Pug Mill was used to mix the aggregate and cement. The mixed material was hauled to the job in bottom dump trucks, discharged into controlled windrows and spread with a paving machine. The diagram below will help explain the sampling procedure used.

Cross-Section of Windrow



After removing the surface material, samples were taken at each toe of the windrow and at each of the top edges. Samples 1A and 1B, shown on the diagram, were combined and then split to make two test samples. This procedure was duplicated on the opposite side of the windrow. The acid-base titration test method was used.

Project Two:

A continuous feed Barber-Greene Model 828 Stabilization Mixer was used on Project Two. After mixing the material was hauled to the roadway in bottom dump trucks and discharged into windrows. This material was not sampled in the same manner as on Project One. For this job, sampling was done by hand scooping the material from locations across the windrow. The material on this project was dumped into unsized windrows and later brought to grade with a motor grader equipped with a special blade. Duplicate samples were taken from two points along the windrow at each selected location. The distance between duplicate samples was normally about two feet but varied up to five feet. Each of the duplicate samples was split into two test samples. The constant neutralization test method was used.

<u>Project Three</u>:

The CTB on Project Three was mixed in a Heatherington-Berner continuous plant, hauled to the street in end dump trucks, and dumped directly into a spreader box. Samples were taken after the material was spread on the roadbed, but before compaction. Testing was according to the constant neutralization method.

On each of the three projects, the longitudinal locations for obtaining samples were randomly chosen. On Project Three, where the material was sampled after being spread, the lateral locations were also selected randomly.

Construction experience has shown that each of the machines used on these projects to mix the CTB is capable of adequately batching and mixing if operated properly. It is important that adequate sampling be done to determine the efficiency of the mixing equipment as well as to check the amount of cement being added to the aggregate. A sampling procedure for determining the efficiency of mixers is included in Test Method No. Calif. 338.

ANALYSIS OF DATA

The range in cement content varied from project to project but the overall average content on each project was very close to the amount specified by the Engineer for the particular project.

The initial analysis of the test data on Project Two indicated that either the sampling-testing procedures were in error or there was extremely poor control of the cement distribution. As a result, a re-evaluation of the test data from this project was undertaken and this revealed that the problem was in the sampling and testing procedures. On the basis of the subsequent re-evaluation, certain test results were discarded and the adjusted data presented in this report as Project Two-Adjusted. This re-evaluation is discussed in detail in Appendix A.

The design of this experiment provided an estimate of the variance introduced by the testing process, the sampling process, and the variance inherent in the material being tested. The amount of variance attributed to each of these sources is shown in Figure 1. The small amount of variance attributed to the testing procedure indicates that the test method is reliable and reproducible.

The variance introduced by sampling is about ten times greater for Projects One and Two than for Project Three. As was discussed under "Materials and Procedures" of this report, samples on Projects One and Two were taken from windrows while samples from Project Three were taken from in-place uncompacted material. Although it is not possible to draw definite conclusions from the limited information available, this study does indicate that less variance is introduced when sampling after the aggregate is spread.

Among the sources of variance, the actual variations in the cement content is by far the greatest single source. The extent of this variance differs greatly from project to project as seen in Figure 1.

DISCUSSION OF PRESENT CONTROL PROCEDURES

According to the 1964 edition of the Standard Specifications of the California Division of Highways, the cement content of plant-mixed CTB is not to vary from the cement content designated by the Engineer by more than ± 0.4 percent based on the weight of the aggregate. The histogram presented in Figure 2 shows the range of cement content and the distribution of results for the three projects.

The basic premise of this study is that all samples were obtained from presently acceptable construction. All material included in this survey was accepted by the Resident Engineer using independent inspection and testing procedures. The sampling procedures used for this investigation were the same as those used for construction control.

As shown in Figure 3, approximately 31 percent of the CTB placed on Project One did not meet the ± 0.4 percent requirement. On Project Two, after adjusting the data, it was found that approximately 48 percent of the material was beyond this limitation. On Project Three only 15 percent was found to exceed this requirement. These values were based on the calculated standard deviation and the assumption that the material was normally distributed.

Routine test results, gathered independently of this study from many projects throughout the State since the adoption of the test method, show a reduction in the overall variation in cement distribution in CTB after the adoption of this test. Figure 4 demonstrates this improvement. Presently, approximately 20 percent of all routine job control tests fall beyond the specification limits, that is, outside of ± 0.4 percent of the intended cement content. These, of course, were not randomly selected samples. The random samples taken for this survey indicated an average of 30 percent outside the limits for the three projects studied.

Both the test data gathered for this study and the distribution shown in Figure 4 indicate that the present requirements on the cement content for CTB are not being completely met. On each of the three projects, all the normal field control tests of seven day compressive strength were above the 400 pounds psi design strength. This indicates that cement content is being set high enough to assure sufficient strength, thus compensating for the variation in percent of cement.

There are two related variables that should be considered in the control of CTB. The control can be relaxed providing additional cement is added to compensate for the increase in variation, thus assuring that minimum design standards are met. Since both cement and control cost money, there is a balance point between these two where costs are minimized. The exact determination of this point is beyond the scope of this study.

PROPOSED CONTROL PROCEDURE

Since the limited data of this study indicate that the present limits for control of cement content are restrictive, it follows that the acceptance range for the individual test results should be increased. The curves plotted in Figure 3 show the percent of material on each of the three projects that would be out of specifications at various assumed acceptance limits. Even though each of these projects was considered to represent acceptable construction, it would not be practicable to establish a limit which would encompass all of the test results observed. An allowable variation of $\pm$ 0.8 percent would include nearly all of the material placed on Projects One and Three but would still leave approximately 16 percent of the material outside the specified limits on Project Two.

An allowable variation in cement content of ± 0.8 percent is a reasonable limit which would include nearly all of the material placed on a properly controlled construction project. To suddenly increase the limits by this amount without adding additional restrictions could result in a reduction in quality. In order to prevent this, it is proposed that an additional control be established by specifying that the average of four test results not vary by more than ± 0.4 percent from the intended cement content.[1] The variation in test data, which is obtained by averaging individual random results, is reduced according to the relationship[2], $\sigma_{\bar{x}} = \frac{\sigma}{\sqrt{n}}$. The reduction in variance is apparent to some extent in the control charts of Figure 5. The effect would be even more apparent if the four individual results making up each average represented four separate locations rather than four results from one location.

The schedule for the test method is so arranged that four tests can be performed in approximately the same time required for one test; therefore, four test results can be obtained each time the material is tested.

(1) Average of four independent test results from one test area, not a moving average.
(2) $(\sigma_{\bar{x}})$ - the standard error, or the standard deviation of the mean.
(σ) - the standard deviation of individual test results.
(n) = sample size, in this case 4.

As explained in Appendix A, regardless of the method used to obtain the samples, it is important that the sample be drawn very carefully so that the gradation of the sample will be reasonably consistent with the overall gradation of the material.

With these points in mind, it is suggested that present specifications be changed to the following intent:

1. One sample should always consist of four observations or sub-samples.
2. The limits for test result on any individual sub-sample should be changed from the present ± 0.4 percent to ± 0.8 percent from that designated by the Engineer.
3. The limits of the average cement content of a sample, as determined by averaging the four sub-sample results, shall be within the limits of ± 0.4 percent from that designated by the Engineer.
4. The Resident Engineer should have the prerogative to accept, reject, or correct the Cement Treated Base when an individual result is outside the limit of ± 0.8 percent providing the average is within the established limits.

In addition to the proposed changes of actual control limits, it is also suggested that a more definite frequency of sampling be established. Presently the California Division of Highways Construction Manual requires that samples be taken "as necessary for control". In order to assure proper control, it is suggested that the frequency of sampling be regulated by the degree of operational control indicated by recent tests. A suggested frequency level schedule is given below. On any project sampling should begin at Level 3 and progressively decrease to Level 1. To allow a decrease in sampling frequency, the Engineer must be satisfied that the distribution of cement is being satisfactorily controlled. A minimum of two consecutive samples taken at Level 2 or 3 could provide this assurance.

Level 3 - two or more samples per day

Level 2 - one sample per day

Level 1 - one sample per week

If any sample fails to meet the specifications, the frequency of testing on subsequently placed material should be increased regardless of any action by the Contractor to adjust his operation or replace or improve the out-of-specification material.

The overall average cement content on each of the three projects studied was almost exactly the amount specified for the respective project, therefore, too much cement at one location would indicate inadequate mixing and a deficiency at some other location. Thus the same restrictions should be applied to both the upper and lower limits.

In order to use the suggested procedures effectively, the location for obtaining a sample must be selected by some acceptable random sampling procedure. Each sample should consist of four observations, or sub-samples, obtained according to a pattern which will provide adequate test results to evaluate both the transverse and longitudinal distribution of the cement.

The most desirable time of sampling is after the material has passed through the paving machine or spreader box and before compaction. Samples taken at this time will check the combined efficiency of the mixer and paving machine. If a large variation is found between the sub-samples, indicating poor mixing, it may be necessary to take special (non-control) samples in order to isolate the trouble.

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3. State of California, Department of Public Works, Division of Highways. Standard Specifications. July 1, 1964.

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APPENDIX A

<u>Re-evaluation of Project Two Test Data and Special Study of Material Used on Project Two</u>

The initial analysis of the test data from Project Two indicated that 54 percent of the test results did not meet the specifications for cement content. Because of the extremely wide range in cement content, a special additional investigation was undertaken to re-evaluate the test data and determine the source or sources of the observed variations. The object of this additional study was to explore some of the variables which could have affected the test data and caused the high incidence of out-of-specification tests on this project (Test Method No. Calif. 338). Three main sources of variance were revealed:

1. Establishing the standard curve for determining the cement content. (It was learned that the standard curve had not always been established by the same technician who performed the tests.)
2. Poor sampling or sample preparation.
3. Actual differences in the tested material.

Testing and Analysis of Data

In addition to the re-evaluation of the project data, five samples were procured from various locations within the same commercial material source which supplied aggregate for construction. These samples were processed and tested in the Headquarters Laboratory of the Materials and Research Department.

The five samples from the source were first prepared and subjected to routine grading analysis and sand equivalent tests. These data are presented in Table 1.

The six main objectives listed below were considered in this additional study based on tests on the samples shown in Table 1:

1. Determine the difference in test results with material from various points in the same pit.
2. Determine the difference in test results due to changes in the curing periods (1/2 and 1 hour selected as extreme values). Normal field time between mixing and testing was about 1/2 hour.
3. Determine the difference in test results due to changes in moisture content (6 and 8 percent used). Normal field moisture was around 7 percent.

4. Determine the difference between operators.
5. Determine accuracy of test on simulated field samples (3,000 grams) with varying percentages of cement.
6. Determine effect of grading on test samples.

The experiment was designed using analysis of variance. Objectives 1, 2, and 3 were studied using the statistical method and Objectives 4, 5, and 6 were handled separately.

TABLE 1

Site Samples from Project Two Materials Source

	66 - 1749	66 - 1750	66 - 1751	66 - 1752	66 - 1753
	Old Stockpile in Place Since Spring 1965 (A)	Stockpile Being Made , 4-66 (B)	North End of Quarry (C)	Center of Quarry (D)	Center of Quarry (E)
	As Rec'd	As Rec'd	As Rec'd	As Rec'd*	As Rec'd*
2-1/2					100
2				100	95
1-1/2		100	100	91	90
1	100	98	98	80	80
3/4	98	95	94	71	69
1/2	86	87	81	61	58
3/8	67	64	68	54	50
4	40	31	56	42	35
8	28	19	49	34	25
16	20	12	34	27	17
30	15	9	22	22	12
50	12	6	13	18	9
100	10	4	8	16	7
200	8	3	6	13	6
SE	35	50	53	---	---

*The retained one-inch sieve material of these samples was crushed and recombined. Petrographic analysis on the various sieve sizes of samples 66-1749, 1750, and 1751, indicate limestone in varying amounts from about 50 to 100 percent.

Objectives 1, 2, and 3: Difference Between Material, Curing Periods and Moisture Content

In this analysis, the term "is or is not significant" means that the treatment, change in moisture, curing time, etc., did or did not significantly affect the test results at the 95 percent confidence level.

The data was collected in a random manner to eliminate uncontrollable or unknown variables such as equipment reliability and operator effect. The data is shown on Table 2 and the analysis on Table 3. The following conclusions were drawn from this data.

1. The samples come from three different populations, (A), (B and C), and (D and E), see Table 1.
2. Moisture is not a significant variable between 6 and 8 percent.
3. Loose curing time is not a significant variable between 1/2 and 1 hour.
4. Interaction between samples and moisture is not significant.
5. Interaction between samples and loose curing time is not significant.
6. Interaction between loose curing time and moisture is not significant.
7. Interaction between samples, loose curing time, and moisture is not significant.

Objective 4: Difference Between Operators

A review of the test data accumulated during construction of Project Two revealed that in many instances the field control tests were performed by one technician while the calibration curve was determined by a second technician. The data from tests performed by the field personnel on Project Two have been separated into two categories: one where the calibration curves and field tests were determined by different technicians, and the other where the same technician performed both portions of the test. These data are plotted in Figure 1A and show that when the calibration curve and field tests are performed by one operator, the tests are more consistent. Approximately 70 percent of the tests were out of specification when the curves and tests were determined by different operators, while 40 percent* were out of specification when the same operator made both determinations.

Laboratory tests also indicated that a considerable difference in test results can develop when duplicate tests on this material are performed by different operators.

*This value based on actual count and differs slightly with value in "Discussion of Present Control Procedures", which was calculated on the basis the material was normally distributed using the determined values for the average and standard deviation.

TABLE 2

Analyses to Determine the Affect of Changing Curing Time and Moisture Content on Various Materials from One Materials Site

Milliliters of Titrated Hydrochloric Acid

	Location A		Location B		Location C		Location D		Location E	
Sample	66-1749		66-1750		66-1751		66-1752&A		66-1753&A	
Curing Time	1/2 hr.	1 hr.	1/2 hr.	1 hr.	1/2 hr.	1 hr.	1/2 hr.	1 hr.	1/2 hr.	1 hr.
[illegible]	78.5	76.5	64.0	68.0	66.0	64.0	80.5	78.5	79.0	82.5
	71.0	77.5	64.5	70.5	64.5	64.5	84.5	80.5	86.0	82.0
[illegible]	73.5	71.5	64.5	65.5	67.0	64.0	88.0	79.0	81.5	83.0
	70.5	77.0	63.5	64.0	64.0	63.0	84.5	85.0	88.0	83.0

TABLE 3

Analysis of Variance

Data from Table 2

		Sum of Squares (SS)	Degrees of Freedom (DF)	Mean Square (MS) SS/DF	Variance Ratio MS÷6.96	F-Value
Type of Material	Column (C)	2,527.10	4	631.80	90.78	2.87
5 & 8 % Moisture	Row (R)	0.30	1	0.30	0.04	4.35
1/2 hr. & 1 hr. [illegible] Curing Time	Group (G)	0.40	1	0.40	0.06	4.35
Interaction	CR	50.44	4	12.61	1.81	2.87
"	CG	61.55	4	15.39	2.21	2.87
"	RG	6.35	1	6.35	0.91	4.35
"	CRG	120.75	4	0.60	0.09	2.87
Residual (Experimental Error)	E	20.91	20	6.96		
Total		2,787.8	39			

Probability = 95%

A second operator (B) performed duplicate tests on the five pit samples discussed above. A comparison of test results by the two operators is presented in Table 4.

TABLE 4

5 Percent Cement Used

	Mls. of Acid Used in Test				
	66-1749	66-1750	66-1751	66-1752	66-1753
Operator A	74.5	65.6	64.5	82.6	83.1
Operator B	57.5	56.8	56.0	58.8	61.3

Operator A-Each result is the average of 8 tests. (From Table 2)
Operator B-Each result is the average of 2 tests.

This data in Table 4 show considerable difference between samples of the material when the titration test is performed by Operator A, but results by Operator B do not show as great a difference between the samples. The differences, however, between Operators A and B are quite large. The final results obtained by the different operators compare favorably when each operator completes the test using his own standard curve.

As a comparison, the following Table 5 shows a tabulation of mls. of acid used for determining the calibration curve by [illegible]

TABLE 5

5 Percent Cement Used

Operator A	9-14-64	9-16-64	9-17-64	10-2-64	10-27-64	11-4-64	Avg.
	61.7	64.3	59.0	60.0	58.0	56.5	59.9
Operator B	9-15-64	10-1-64	10-5-64	10-24-64	11-23-64		
	58.5	69.0	67.5	64.5	61.0		64.1

Test data are average of three tests.

Objective 5: Tests on Simulated Field Samples

Table 6 shows results of tests performed by Operator B on laboratory prepared simulated field samples (3,000 grams) broken down to 300 gram test samples. Two test specimens were proportioned from each 3,000 gram sample in all but three cases.

TABLE 6

Test No.	Planned Cement Content %	by Titration % Cement Sample #1	Sample #2
66-1749	3.0	2.8	---
66-1751	4.6	4.1	4.2
	3.0	2.9	2.9
	3.8	3.6	3.6
66-1752	3.8	3.5	---
	3.0	3.0	---
	4.6	4.9	5.0
66-1753	3.8	3.4	3.6
	4.6	4.6	4.6

The data are plotted in Figure [illegible]. Only [illegible] of 15 was less than - 0.4 percent of [illegible] content. There were no [illegible] of the planned cement content.

Objective 6:

Examination of the test data indicates considerable difference in the percent passing the 3/8 inch sieve between calibration curves and field samples.

The grading in itself will not affect titration test results; however, poor sampling and/or sample preparation can have a noticeable effect.

To illustrate this point, 4 percent cement was mixed in a 3,000 gram sample of which 51 percent of the material passed the 3/8 inch sieve. During the 300 gram test specimen preparation, a portion of the material was deliberately misproportioned so that 41 percent passed the 3/8 inch sieve. The percent of cement determined for this portion of the sample was 3.5 percent; the reason being that cement tends to be concentrated in the fines. Figure 3A shows how this can affect the test.

CONCLUSIONS

Examination of the test data from Project [illegible] and the above experiments indicate that there are some items which could have affected the test data. Some of the pertinent points are as follows:

1. Differences in aggregates can cause a large error in test results unless compensated for by determining calibration curves on similar material.
2. When the calibration curve is established by one operator and the actual testing is performed by another, the test result will often be in error.
3. Differences in moisture (6 to 8 percent) and in loose curing time (1/2 to 1 hour) do not cause any errors of significance.
4. An experienced, conscientious operator can reproduce his test results satisfactorily.
5. The importance of careful sample preparation should not be underestimated. There were indications that poor sampling or sample preparation occurred on the project, i.e., Gradings on Figure 6A.

RECOMMENDATIONS

1. Calibration curves should be performed often by the same operator who performs the test.

2. Samples should be procured and processed in a careful manner to assure that the sample actually represents the material.

3. For this research project use only those results where the same operator performed the tests and established the calibration curve. (100 tests as reported in Figure 1A) All other test results should be discarded.

SUMMARY RESULTS

	Project 1	Project 2 (Adjusted)	Project 3
ARITHEMATIC MEAN ($\bar{x}$)	2.46	3.78	3.02
MATERIAL VARIANCE (σ_A^2)	0.066	0.221	0.058
SAMPLING VARIANCE (σ_S^2)	0.067	0.077	0.006
TESTING VARIANCE (σ_T^2)	0.020	0.029	0.014
OVERALL VARIANCE (σ^2)	0.153	0.327	0.078
OVERALL STANDARD DEVIATION (σ)	0.391	0.571	0.279
NUMBER OF OBSERVATIONS (N)	184	100	200

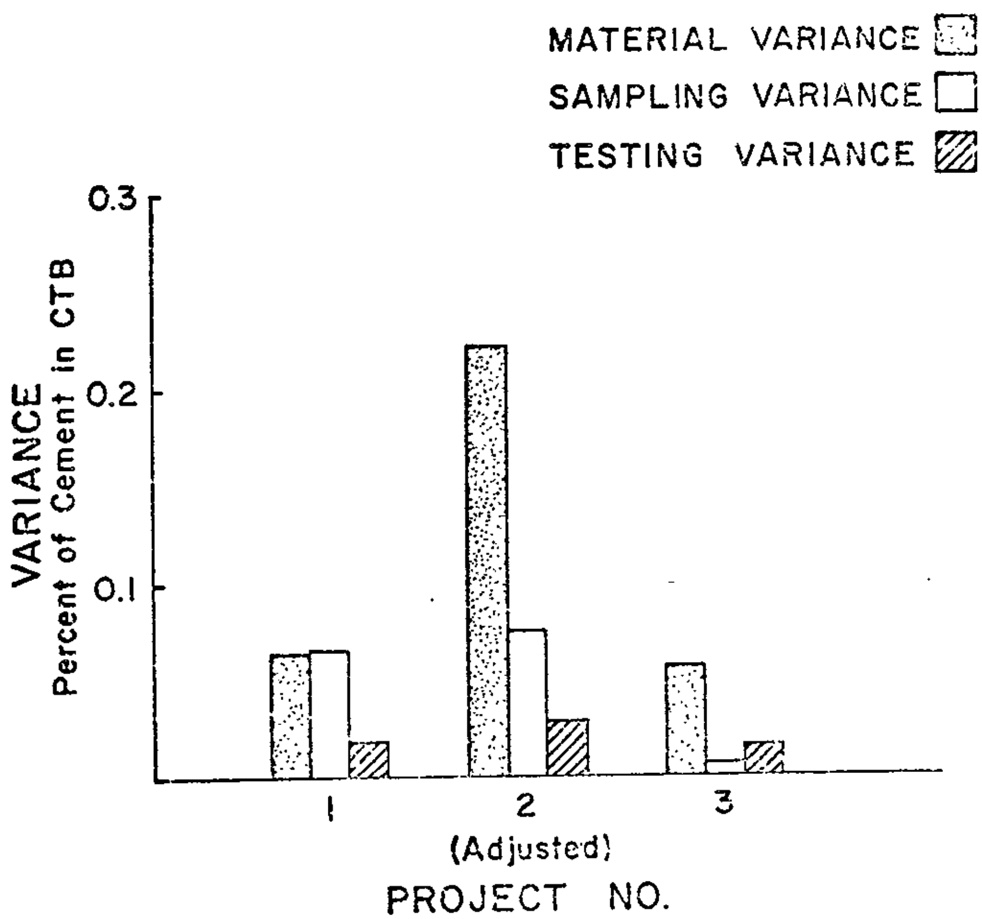
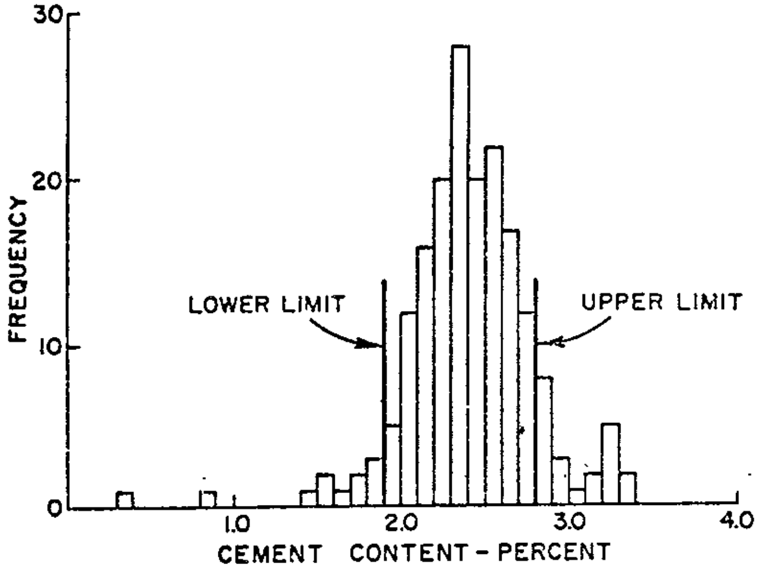
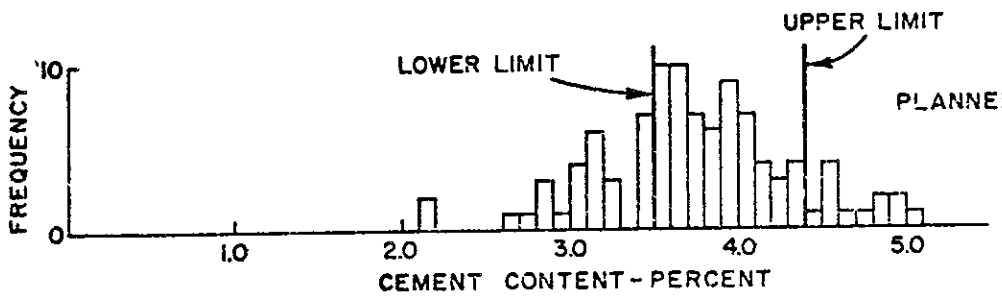


Figure 2



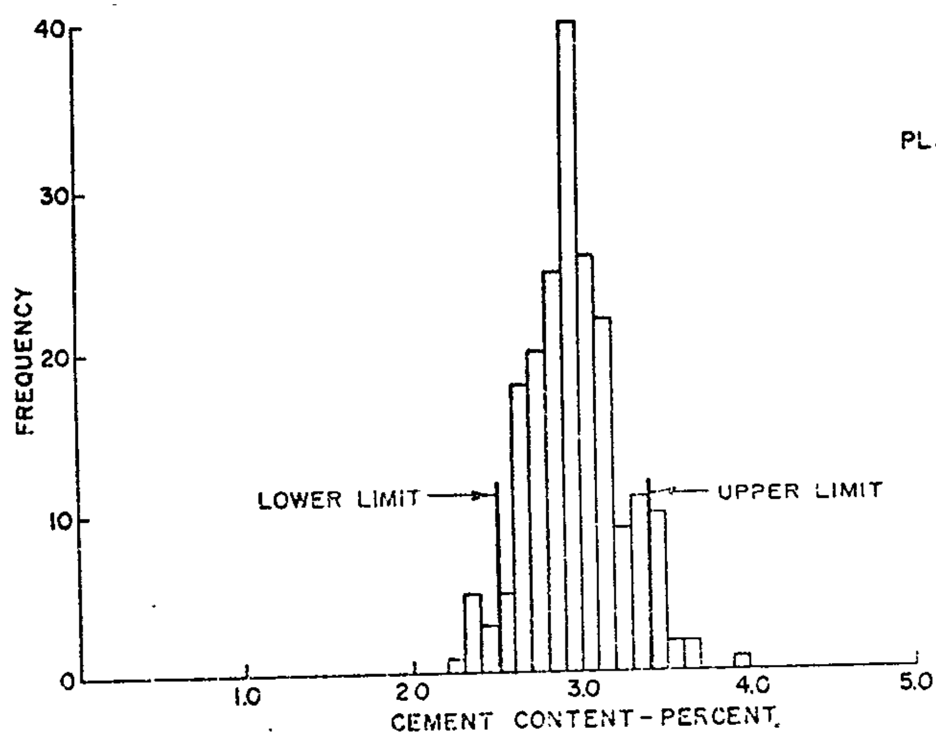
PROJECT I
PLANNED CEMENT CONTENT VARIES USUALLY 2.4%

$\bar{x} = 2.46$
$\sigma = 0.391$
$n = 184$



PROJECT 2
(Adjusted)
PLANNED CEMENT CONTENT 4.0%

$\bar{x} = 3.80$
$\sigma = 0.571$
$n = 100$



PROJECT 3
PLANNED CEMENT CONTENT 3.0%

$\bar{x} = 3.02$
$\sigma = 0.279$
$n = 200$

Figure 3

PERCENT OF MATERIAL OUT OF SPECIFICATIONS AT VARIOUS ASSUMED ACCEPTANCE LIMITS

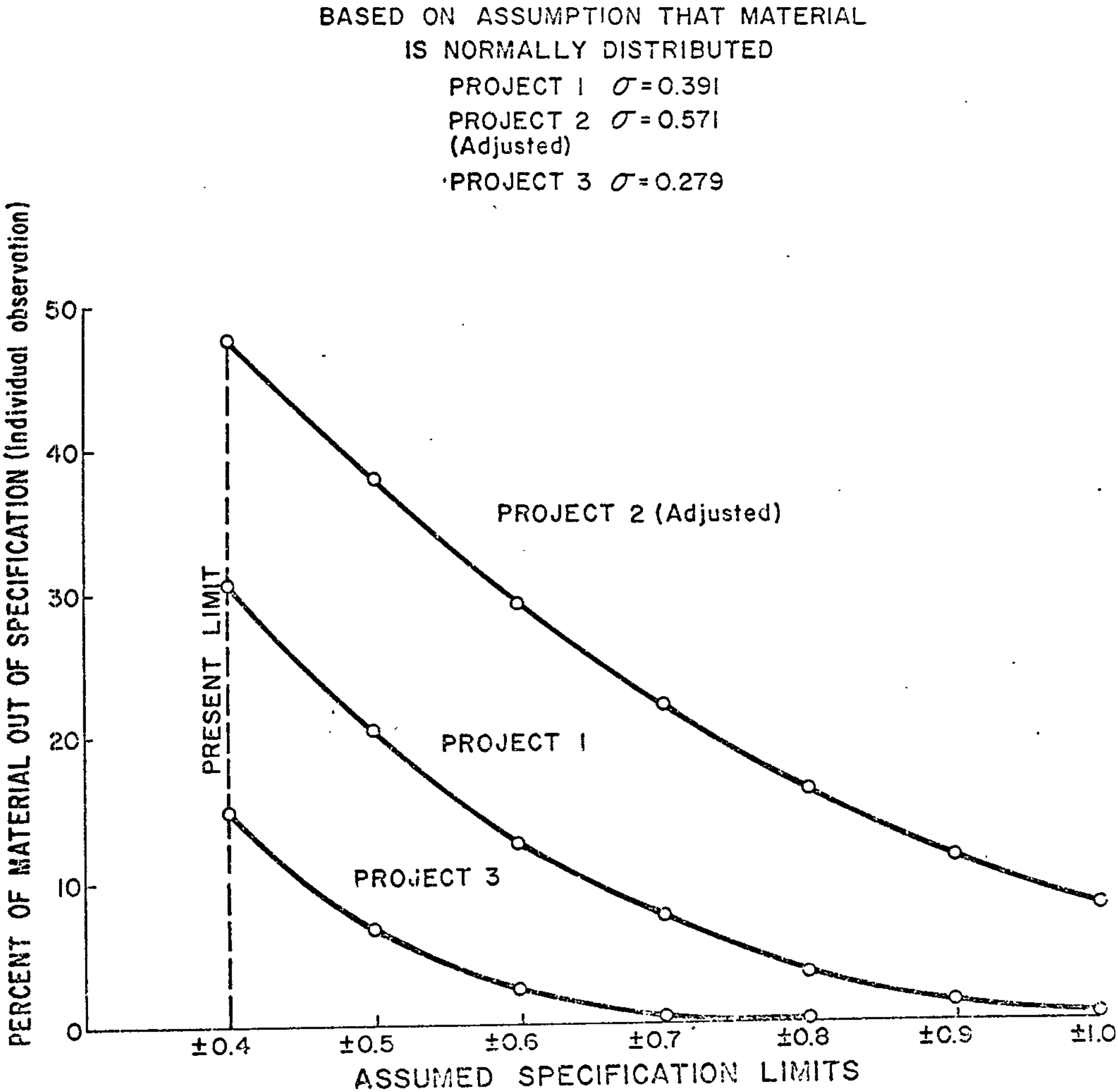
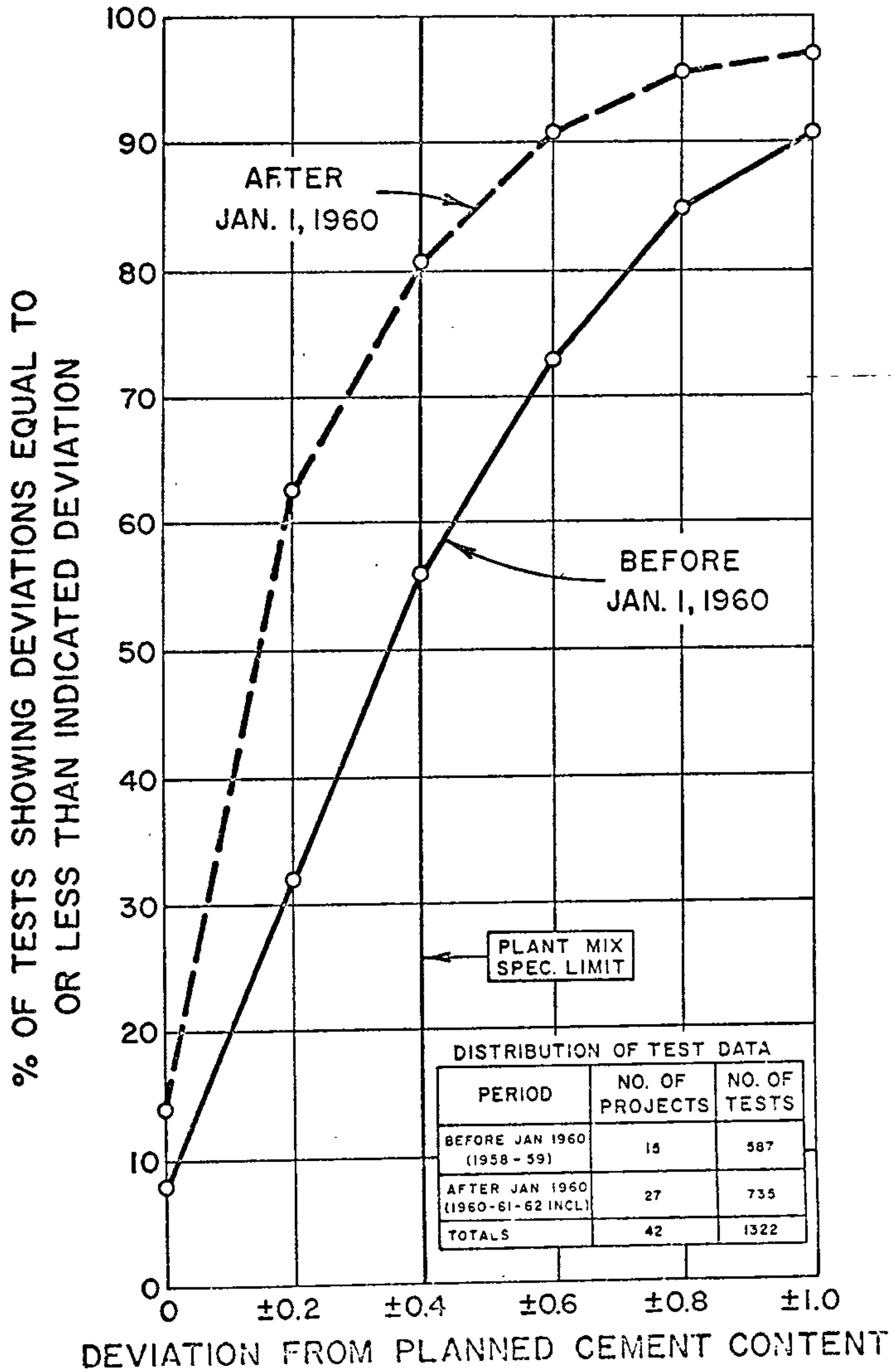


Figure 4

BATCH PLANTS

A CHART DEMONSTRATING THE IMPROVEMENT IN CTB CEMENT DISTRIBUTION WITH THE ADVENT OF THE JAN 1960 STD. SPECS. AND THE USE OF THE TITRATION TEST AS THE METHOD OF CONTROL



DISTRIBUTION OF TEST DATA

PERIOD	NO. OF PROJECTS	NO. OF TESTS
BEFORE JAN 1960 (1958 - 59)	15	587
AFTER JAN 1960 (1960-61-62 INCL)	27	735
TOTALS	42	1322

Figure 5

AVERAGE TEST RESULTS
PROJECT I

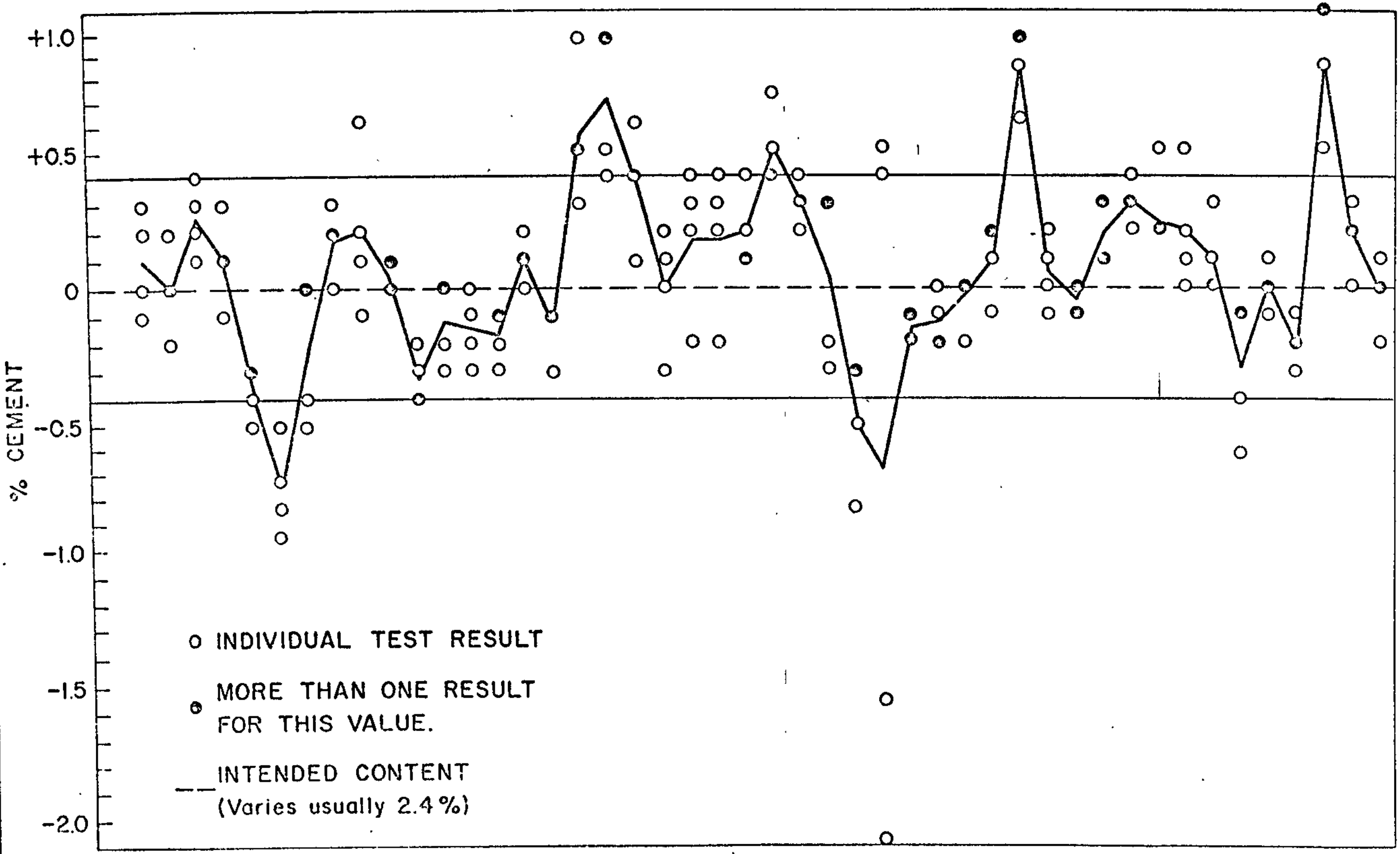
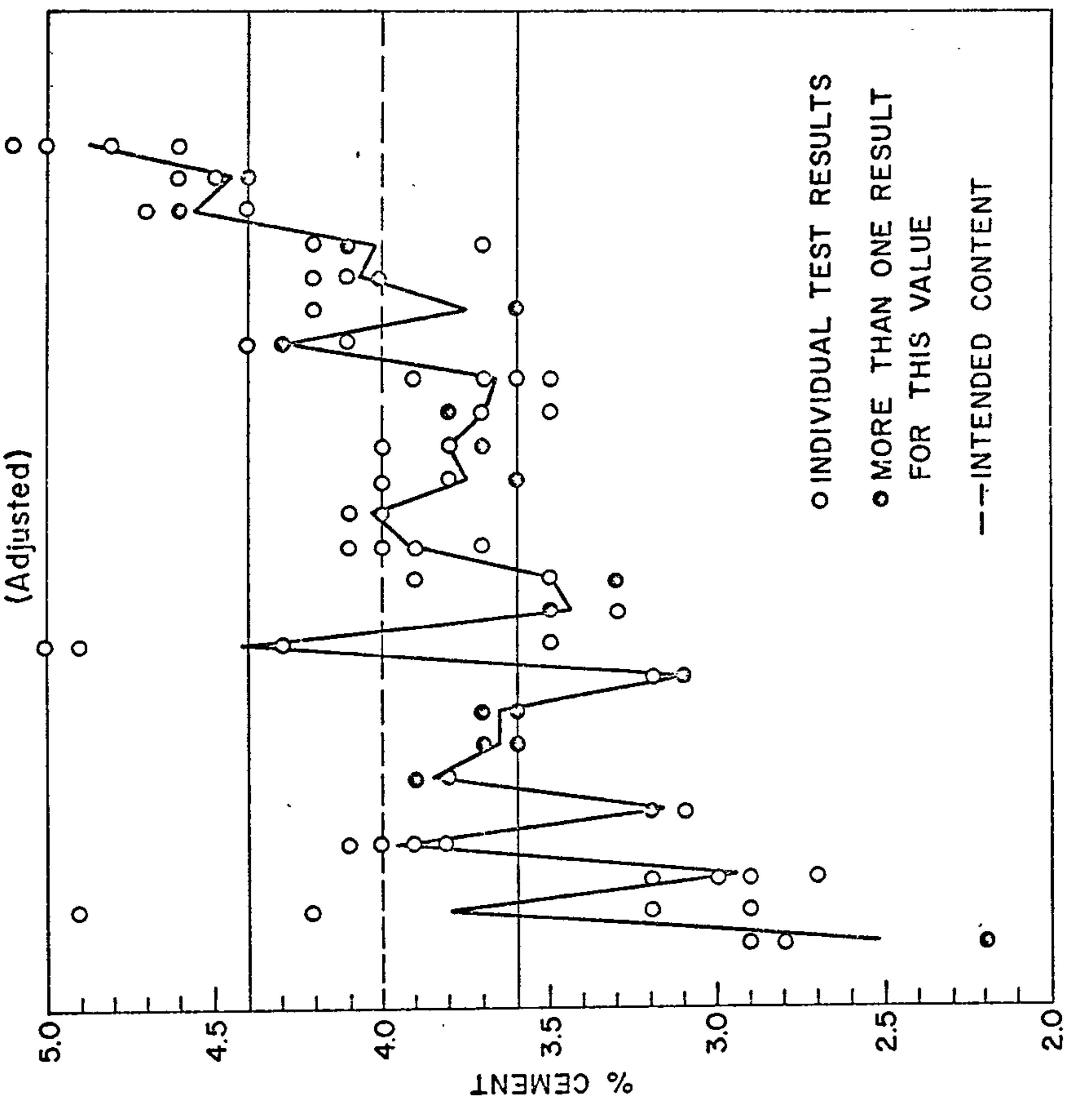


Figure 6

AVERAGE TEST RESULTS
PROJECT 2
(Adjusted)



AVERAGE TEST RESULTS

PROJECT 3

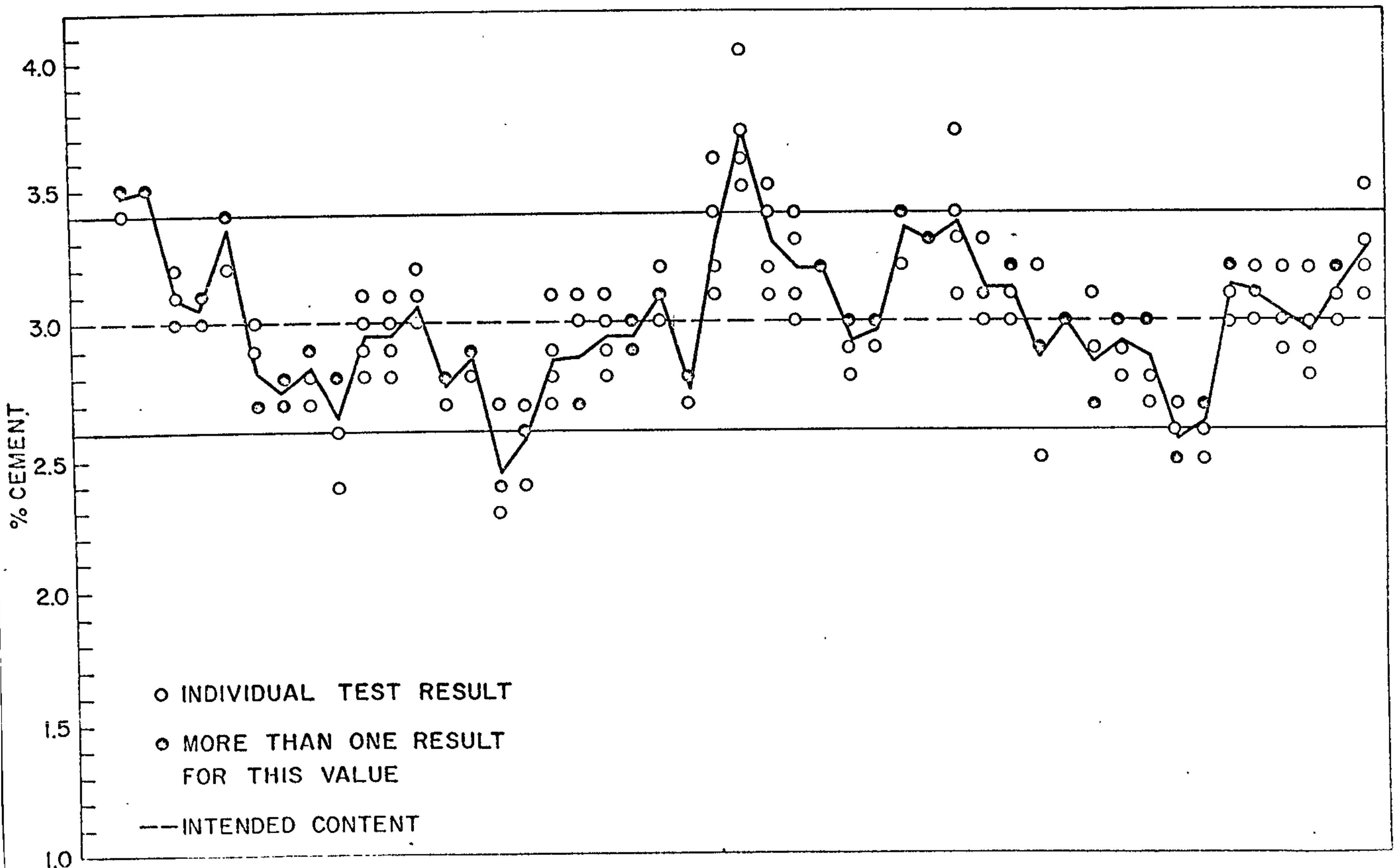


Figure 1A

TITRATION TEST ON PROJECT 2

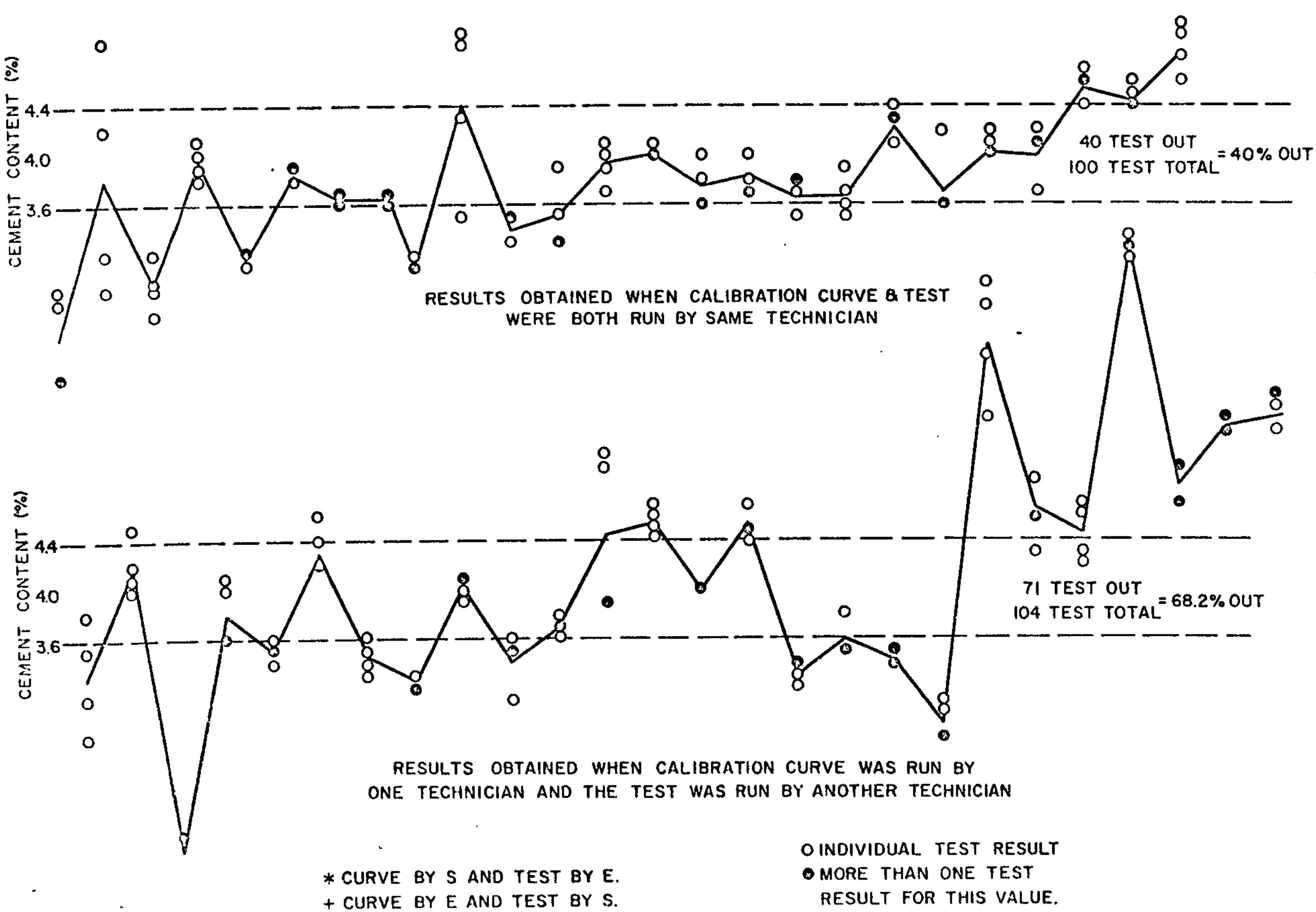
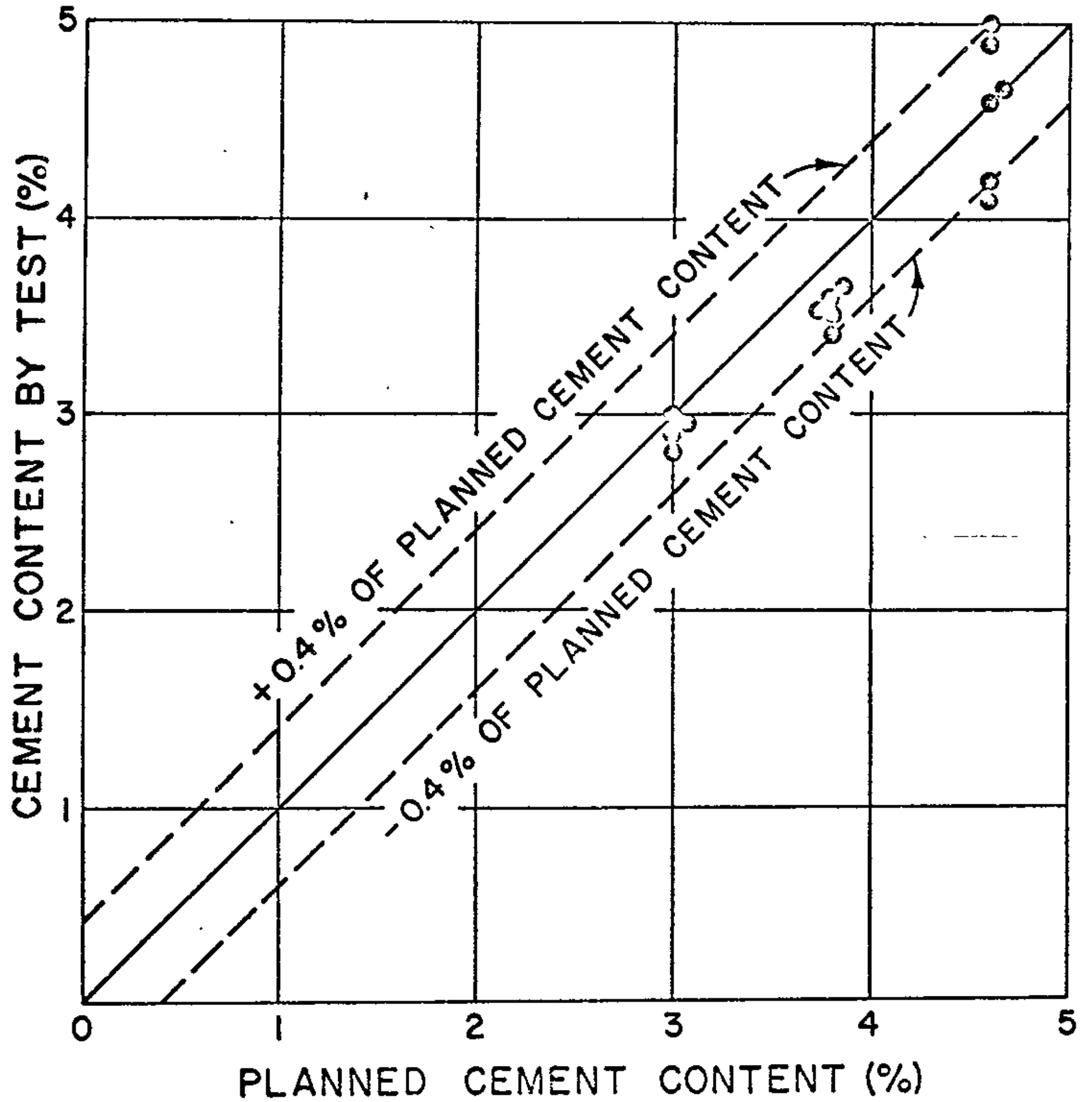


Figure 2A

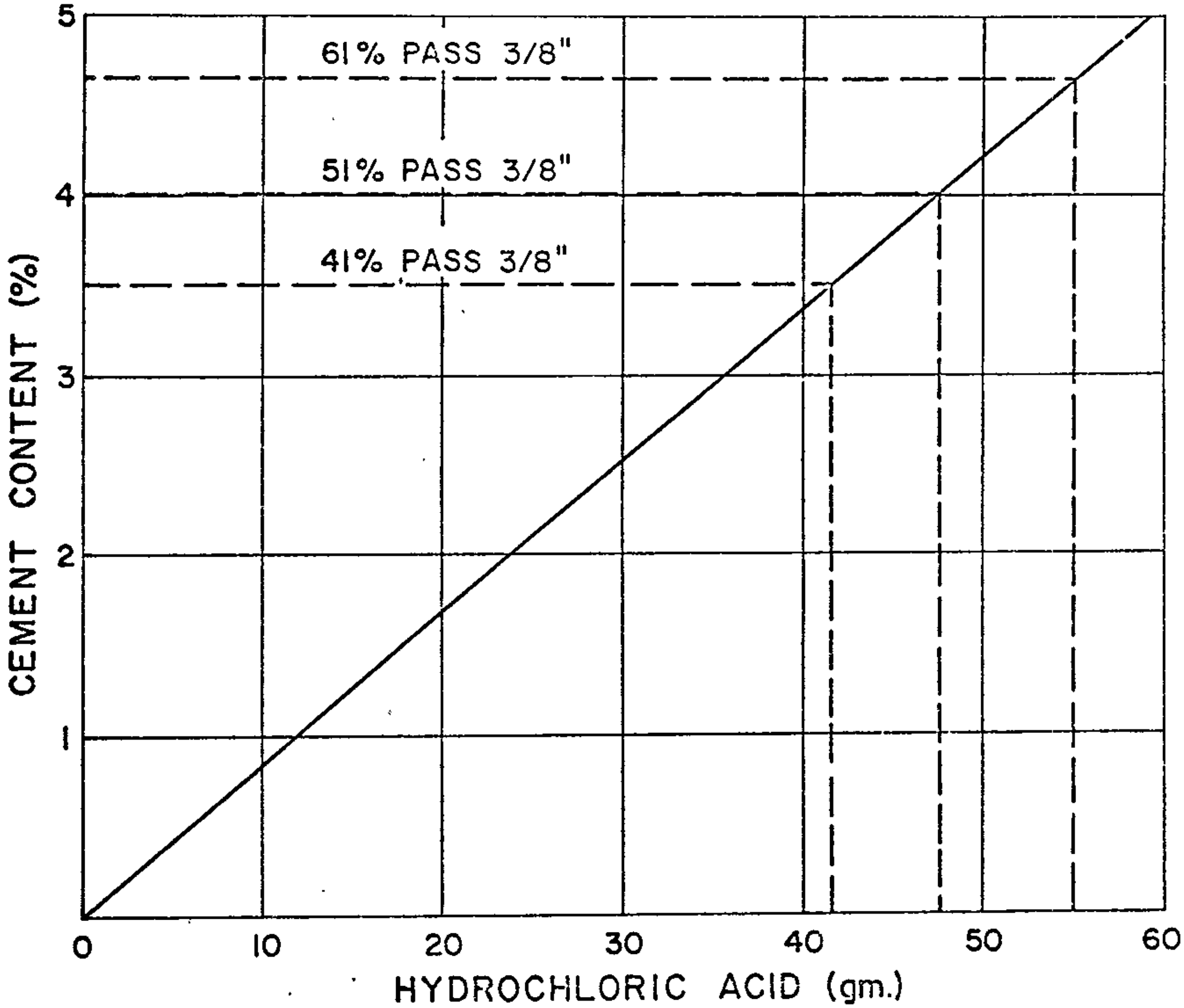
TITRATION TEST ON PROJECT 2 AGGREGATE



3000 GRAM SAMPLES PROPORTIONED DOWN
TO 300 GRAM TEST SPECIMENS.

CONSTANT NEUTRALIZATION TEST

66-1752



VARIATION IN CEMENT CONTENT FROM 4% CEMENT CAUSED BY VARYING THE GRADING.

TESTS PERFORMED ON 300 GRAM SAMPLES PREPARED FROM 3000 GRAM SAMPLES.